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- USSR -

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THE MAIN SOURCE OF SOLAR CORPUSCULAR
STREAMS

E. R. Mustel'

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It became evident rapidly after the discovery of the effect of the sun on the magnetic field of the earth (in the middle of the last century) that this action is basically of a corpuscular nature. Numerous investigations have consequently been made in the meanwhile, in the attempt to find out those regions on the surface of the sun from which the corpuscular streams originate.

As a result of systematic solar observations it has been determined that one of the sources of solar corpuscles is the brightest chromospheric flares of class 3 - and to a lesser extent flares of class 3. The geomagnetic disturbances resulting from the flares have in the majority of cases a sudden commencement.

Judging on the whole, chromospheric disturbances produce only a relatively small number of geomagnetic disturbances (in comparison with the total number of disturbances during an 11-year cycle), whereupon these disturbances occur primarily in years which are near to maximum solar activity. Besides the chromospheric flares,

There is apparently still another source of geomagnetic disturbance with sudden commencement, namely radio-emission spots of certain types (1).

However, the greatest amount of geomagnetic disturbances, if the entire solar activity cycle is considered, are made up of corpuscular streams of a completely different origin (see (2)). The disturbances under consideration which, as is often done, we will term M-disturbances, are distinguished by rather gradual commencement ordinarily, strongly pronounced 27-day recurrence and seasonal variations with two equinoctial maxima. The corpuscular streams which create M-disturbances are especially important in years which precede maxima of solar activity (2). During this period the duration of individual M-disturbances can reach large values, lasting up to 10-12 days; it is these which produce for prolonged intervals of time practically continuous (particularly in the Arctic regions) disruption of shortwave radio communication. Nevertheless, M-disturbances are rather frequent even during the years of maximum solar activity; actually, seasonal variations in geomagnetic activity are by and large sharply pronounced in these years as well (3). Disturbances with sudden commencement do not in the majority of cases produce seasonal variations.

Hence, M-disturbances are the basic form of geomagnetic disturbance in number and, especially, in the time which they take up during the course of an entire solar cycle. Correspondingly, the corpuscular streams which produce these disturbances are (from the practical viewpoint) the basic form of streams disrupting short-wave radio communication, causing polar aurorae, etc.

The author of this article discovered at the beginning of 1942 (4) that passage through the solar disk's visible center of every calcium flocculus (or facula) is accompanied for some time Δt by geomagnetic disturbances. Together with this, the central meridian passage of the flocculi, although at a considerable distance from the center of the solar disk (greater than $3-5^\circ$) did not show the usual indicated effect. The conclusion has been drawn in regard to this that the flocculi are the source of approximately radial corpuscular streams.

The deductions which have been formulated in (4) were confirmed by further investigations. A part of these studies have been based on direct comparisons of flocculi with geomagnetic disturbances (5-9), while another part has been based on the application of statistics (10, 11).

The disturbances which have been treated in the indicated research are principally M-disturbances; hence, flocculi appear as the source of the latter, or more precisely, the nearly radial corpuscular streams issuing from them. This, in particular, explains the 27-day recurrence of M-disturbances (5-8), the seasonal variations in the frequency and intensity of geomagnetic disturbances (2,8), and other effects which testify to the presence of radial emission of the gas streams which produce the M-disturbances (2).

Further work on this particular problem should include an explanation of the mechanism of the emission of corpuscles from the flocculi. We will consider this in greater detail.

It should be pointed out in the first place that in the prominences on the solar disk (in its more centralized regions) the flocculus limits coincide approximately with the limits of the bright coronal area in line

5303 A which occurs over it, and what is especially important, with the limits of the bipolar (or unipolar) magnetic area *. The question thus arises as to which of the three forms of solar activity is the basis for the ejection of the corpuscles: floccular emission, the corona above the flocculus or the local magnetic field of the active region. Observations indicate that the basis here is apparently the latter factor - the magnetic field. Actually, in many cases before the end of a long geomagnetic sequence the flocculus which creates this sequence disappears, although the sequence lasts for two to three rotations longer without being accompanied by any visible (optical) manifestations of solar activity at the corresponding longitude. On the other hand, the local magnetic field ordinarily behaves in the following manner (12, 13). After the disappearance of all "optical" forms of solar activity (floccular spots, bright coronal emission, etc.) from the active area, the magnetic field of a bipolar nature which has hitherto existed in this area is replaced by a field of a unipolar character which is observed for several rotations more. The inference may be drawn from this that in actuality the emission of corpuscles from the active region determines its magnetic field and that the last members of a geomagnetic sequence, observed without the occurrence of

* All this comprises, as it were, the "basis" of the active area, within which there develop still other forms of solar activity - spots, flares, protuberances, etc.

flocculi and in the bright corona at $\lambda 5303 \text{ \AA}$, brought about by unipolar magnetic areas. This conclusion has been corroborated in particular by direct comparison of geomagnetic disturbances with flocculi and local magnetic areas on the sun (8).

From the standpoint of the conclusions drawn, the ejection of corpuscles is determined solely by the occurrence of a local magnetic field in the active area, and regardless of the nature (bipolar or unipolar) or sign of the field. This immediately suggests that the ejection of corpuscles here (evidently of individual gas condensations) might be connected with the diamagnetism of the ionized gas (14, 15), although it is difficult to say at present in what form this diamagnetism occurs in the given case.

Naturally, however, the diamagnetic mechanism is not the only possible solution to the problem under examination. To arrive at any final conclusions it is necessary to have made a thorough study of the properties of these corpuscular streams created by the M-disturbances.

It should first of all be borne in mind that for each cycle the average velocity \bar{v} of the corpuscles which produce the indicated disturbances decreases with the phase of solar activity t ; at moments close to maximum activity, the velocity \bar{v} can attain magnitudes of 500 km/sec, and even before the minimum activity \bar{v} drops to values of 150-200 km/sec (5, 11). Together with this, as a comparison of the dependence of \bar{v} on t for different cycles shows (see especially figs. 1b and 3b in (11)), we cannot obtain a single general curve which connects \bar{v} and the activity phase. This is without any doubt a result of the fact that the value \bar{v} does not actually depend on the phase in the cycle (i.e. on time), but rather on the absolute level of solar activity. And in reality, if rather than using time as the axis of abscissas, some measure of solar activity were employed, as for instance the relative number of sunspots R which is taken, naturally, according to its curve for each individual cycle, the dependence of \bar{v} on R will be nearly identical for all cycles *. This attests to the fact, as one can well suppose, that the value \bar{v} depends on the mean magnetic intensity H of the active areas, at the same time as this value H is statistically related to the absolute solar activity level. Both assumptions are wholly natural. In particular, the greater the field intensity of the area, the higher ejection velocities may be anticipated (for example with diamagnetic mechanisms).

Another parameter which characterizes the corpuscular streams is the full velocity range of corpuscles in the stream Δv . According to (8) the value of Δv is relatively small, averaging around 150-200 km/sec, and does not change to any marked degree with the phase of solar activity (see fig. 3 d in (11)). The stability of Δv in time may apparently be interpreted by the velocity spectrum, judging on the whole, being determined by non-homogeneities in the structure of the active areas, as well as by heterogeneities having identical natures, as follows from observations, in all phases of solar activity.

It is interesting to note that the approximate constancy (in time) of the value Δv and the simultaneous decrease of V with the phase (more precisely, with the activity level) are explained completely naturally (16) by the fact that the average duration of ΔT of a single M-disturbance increases with the phase of the cycle, attaining the above mentioned values in the order of $10^4 - 12^4$. This explanation of the growth ΔT with the phase t (at approximately constant Δv .) may also be considered as an independent confirmation of the accuracy, found in (4), of the connection between the flocculi and geomagnetic activity.

An important fact which follows from this is that the flow of corpuscles from the flocculi is practically independent of the presence of sunspots in them (7, 11). This circumstance is apparently linked to the fact that (as can be deduced from an examination of magnetograms of the active areas which have been taken at the Crimean Astrophysical Observatory) the area occupied by a spot and the activity sphere of its magnetic field is usually small in comparison with the area and dimensions of the entire active area (of the flocculus).

An explanation of the radially of corpuscular ejection from the flocculi is of extreme importance. It is possible that the basis of this may be found in the approximate radially and rectilinearity of the coronal forms (of rays) above the flocculi (17). If the indicated forms are characterized by magnetic force lines in the corona, it is naturally to expect that the gas condensations examined above will move (under the action of

* [Carried over from page 4.] The greatest divergences occur at the most minimal activity. This apparently indicates that the value R is not a sufficiently accurate index of solar activity.

diamagnetic or other forces) along these lines.

Particular attention should also be turned to a study of the physical state of these condensations which comprise the corpuscular streams. At least a part of these condensations should have their own congealed magnetic field. This is vouched for, not only by a study of variations in the intensity of cosmic rays, but also by an analysis of geomagnetic disturbances (16). The very fact that the level of variation in the earth's magnetic field during prolonged disturbance remains practically unchanged testifies to the fact that under these circumstances the kinetic energy of the gradual movement of gas condensations in the corpuscular streams is not the basic kind of energy in these condensations. Actually, the velocity of the corpuscles which participate in creating the commencement of a disturbance should be larger than the velocity of the corpuscles which produce the end of a disturbance. Corresponding computations show that in many cases the kinetic energy of the corpuscles at the end of a disturbance should be an order less than the kinetic energy of the corpuscles at the commencement of disturbance. It is therefore natural to assume that in such cases the basic kind of energy is the energy of a congealed magnetic condensation field.

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